THE DARWIN WORKSPACE ENVIRONMENT FOR REMOTE ACCESS TO AERONAUTICS DATA

Joan D. Walton,* David J. Korsmeyer†
NASA Ames Research Center
Moffett Field, CA 94035

Rajesh K. Batra,‡ Yuval Levy§
Stanford University
Stanford, CA 94305

Abstract

In a collaborative effort between researchers at the NASA Ames Research Center and Stanford University, information technologies are being applied to the problem of improving the design process for the aeronautics industry. Two prototype systems developed by the participants address enhancing the utility of both experimental and numerical data. The DARWIN Workspace Environment (DWE) is a powerful system for remotely accessing and reviewing wind tunnel test data, while the Integrated Computational System (ICS) provides innovative tools for extracting and visualizing flow features from computational solutions. The hosting of the ICS within the DWE demonstrates the future capability of remote aeronautics design analysis.

Introduction

Traditionally, a wind-tunnel test requires bringing a team of technicians and engineers to the tunnel location. The engineers, needed for their expertise, must travel to the test site to have access to the data. Gathering the complete results of the test and interpreting the data is time consuming and can take up to six months. The results often provide valuable insights and reveal areas and issues that could have been explored during the test if those results had been immediately available. By the time the data reaches aerospace industry customers, however, it would be necessary to arrange for another wind tunnel test to obtain further information.

NASA Ames Research Center is using information systems technology for developmental aeronautics to redefine the classic wind-tunnel test. The goal of the project, called Developmental Aeronautics Revolutionizing Wind-tunnels with Intelligent Systems of NASA (DARWIN),[1] is to reduce the design-cycle time for industry customers by improving speed and quality of access to experimental data and by providing tools for integration and interpretation of numerical simulation results. The strength and promise of this program is the potential for greatly improved understanding of an aircraft's design through standardized integration of experimental and numerical disciplines.

This paper will describe two components of this effort to reduce the design cycle time for the aeronautics industry. The first component is the DARWIN Workspace Environment (DWE), which is the user interface to the DARWIN system. By harnessing current internet technologies, data visualization tools, and database access methods, the DWE empowers users to access, review and analyze experimental data quickly and efficiently. The second component is the Integrated Computational System (ICS), which incorporates advanced techniques in feature extraction and data visualization to facilitate the analysis and assessment of numerical simulation data. From a numerical solution, the feature recognition component of the ICS can automatically identify and display a variety of flow features, such as shocks and vortices. Finally, we will discuss plans to integrate these two efforts to provide a system for comparing experimental and numerical results.

Overview

DARWIN provides remote access to the NASA Ames wind tunnels facilities through a dedicated, site-wide fiber optic intranet. No connections to the open Internet are permitted on DARWINnet. The use of these isolated networks and subnets within them are the first level of security that DARWIN provides. User authentication is determined via a password specific to the industrial partner and the particular test. The machine internet protocol (IP) address is also used to authenticate the user and the company. Data privacy and security are maintained through the use of separate and secure data channels for each of the wind tunnel tests regardless of the user. Each test user is provided with an encryption key that is valid only for the specific test. Combining these various techniques (isolation, authentication, and

---

* Computer Scientist, Computational Sciences Division.

† Senior Project Scientist, Computational Sciences Division. Member AIAA.

‡ Graduate Student, Aeronautics and Astronautics Department, Stanford University.

§ Research Associate, Aeronautics and Astronautics Department, Stanford University. Member AIAA.

encryption), DARWIN provides a robust level of security to the data provided for the remote user.[2]

The DARWIN system was used to support two tunnel tests at NASA Ames in 1996 and currently has the architecture diagrammed in Figure 1. The DARWIN server hosts a web server and a meta database. The meta database contains the search criteria for retrieving experimental data and pointers to the locations in the DARWIN file system of the raw data files. The ServIO server is located in the tunnel and hosts the ServIO system and the raw data files for the test. During a wind tunnel test, ServIO automatically generates the raw data files plus namelist files that are used to load the DARWIN meta database with the search criteria and the locations for those files.[3] When DARWIN customers want to access the experimental data, they use a Distributed Remote Access Machine (DReAM) client, which is an SGI workstation that is configured with a web browser, DARWIN executive software, and supplementary analysis tools.[2] When a customer requests the web pages for a particular tunnel test, the DARWIN web server queries the meta database via common gateway interface (CGI) scripts and returns hypertext markup language (HTML) documents that describe and display the experimental data. The DARWIN Executive and analysis tools are resident on the DReAM client and can be utilized for in-depth review of the data (Figure 2).

The ICS is composed of three levels: the solver level, the feature extraction level, and the display level. The solver level allows the engineer to set up a new case and to launch the flow solver. The feature extraction level includes algorithms to extract the main flow features such as shocks, vortex cores, and skin-friction lines. In addition, it includes the capability to visualize tensor fields such as the deformation tensor and Reynolds stress tensor. The display can be launched separately as an independent application and provides various viewing capabilities that are further discussed later. The ICS is currently in use by the scientific visualization group in the Aeronautics and Astronautics Department at Stanford University.

The DWE is configured to act as a host for the ICS helper applications and to natively access and launch the appropriate ICS components remotely via the internet.

DWE Technologies

The DWE applies a variety of technologies to the problem of providing fast, high-quality data-analysis tools to users at remote sites. Internet technologies developed for the world-wide web are combined with specialized analysis tools to build the optimum environment for review of wind tunnel data.

Web-based Tools

The DWE component of the DARWIN system is comprised of a web browser that can display HTML pages (containing text, JavaScript code, and Java applets), the DARWIN executive software, and a collection of software applications for performing specialized data analysis, visualization, and collaboration tasks. The browser, the DARWIN executive, and the tool kit applications are all resident on the customer's workstation. The HTML pages, which can be static documents or the dynamic results of CGI scripts or JavaScript functions, are retrieved from the DARWIN server via secure hyper text transport protocol (HTTP).

The DWE makes full use of the latest web techniques and software. All interactions between DARWIN users and the DARWIN system are through the web browser. Because of the growing popularity of the Internet and web "surfing," the browser environment has the advantage of a familiar look and feel for many users. In addition, the Netscape 3.x browser, which was chosen for this project, runs on multiple platforms, including personal computers as well as high-end workstations. Thus, though advanced data analysis is reserved for users with access to Silicon Graphics workstations, the basic functions of the DWE are available to users on any platform.

To access data from a particular wind tunnel test, a DARWIN user logs in to the system by requesting the login page from the DARWIN server and then entering a user name and password. The IP address of the requesting computer is also checked against a list of allowed machines before access is granted. Once logged in to the DARWIN system, the user is presented with links to the tests that he is permitted to review (Figure 3). The web site for a wind tunnel test contains a summary of the test's purpose, statement of progress, and various views on the data collected so far.

The majority of the HTML content displayed by the DWE is generated by server-side common gateway interface (CGI) scripts. The scripts, written in Perl, verify the user's permission to access the given test, and then query the DARWIN database to retrieve the requested information. The SybPerl extension to Perl is used for database communications, as the DARWIN database is implemented using Sybase. All database queries are standard SQL, but the SybPerl commands used to transmit the queries to the database are Sybase specific. A benefit of generating the HTML pages directly from the database is the pages are always up-to-date. During a tunnel test, the database can be updated every five to ten minutes, and any changes are automatically reflected in the DARWIN web pages.

The CGI scripts generate pages that contain standard HTML commands, but also Java applets and JavaScript calls that add functionality to the display. The code for Java applets is stored on the server until the browser encounters an applet tag in the HTML that it is processing. At that point, the browser downloads the applet code from the server and runs it locally on the client's machine. Downloading the applet can sometimes take a minute or two, but once resident on the user's machine, the applet can run without relying on network connections back to the server and can respond quickly to user commands. A graphing applet for plotting two-dimensional data is used in several places in the DWE (Figure 5). The primary advantage of the graphing applet over a static plot image is its interactivity. Among other things, the user can zoom in on a region of the graph, specify x- and y-axis ranges and labels, add or remove data sets from the display, and modify the symbols and colors used in the plot.

A second applet is employed to animate pressure sensitive paint (PSP) images. The animation applet allows the user to loop through a set of images and view changes over the sequence (Figure 6). This method of viewing collections of images highlights subtle changes in color or pattern since each image exactly overlays the next, removing the need to mentally recalibrate position coordinates between images.

JavaScript commands differ from Java applets in that all the instructions for executing the commands are present in the HTML for the page. In the DWE JavaScript is used to automate sequences of tasks that the user could do manually with the browser and to make the pages interactive. For example, JavaScript is used to build push buttons that select all the checkboxes in a list, submit a form, or open a new browser window displaying a particular page. Like Java, JavaScript has the speed advantage of executing on the client machine. Unlike Java, JavaScript is not compiled code. The user may view the JavaScript instructions by asking the browser to display the source for a given page.

The final web technique that is used by the DWE is persistent "cookies." Cookies are small files of specific data that are set by the web server and stored by the client browser. Each cookie has a name (or key) and a value, an expiration date, a domain and a path. The expiration indicates how long the cookie is active, the domain is the server for which the cookie is valid, and the path indicates to which documents the cookie applies. Since cookies are stored by the client browser, they are ideal for recording user preferences. The DWE uses cookies for storing user preferences for a variety of display options, including column headings in tables, graph variable assignments, colors and symbols for plotting data. They are also used to remember state conditions, so that when a user returns to a page he has already visited, he finds it in the same condition as when he left.

Helper Applications

As flexible as the web environment is, it cannot handle all data analysis tasks. For situations where a specialized task or in-depth analysis is required, existing programs (often platform specific) are utilized as "helper applications" to the web browser. Installing a program as a helper application is done by configuring the web server to give certain documents a unique label and then setting the web browser to recognize that those documents should be viewed by a particular application. When the browser is served a document with this unique type, it downloads the document and passes it directly to the appropriate helper application.

The DWE employs a variety of helper applications for data analysis. exVis is a data visualization tool for analyzing PSP images (Figure 7). With exVis, the user can create pressure plots for any line segment on the image. These plots allow users to compare PSP data directly to conventional pressure tap data and to investigate pressures in all exposed regions on the model. For CFD solutions and acoustic data files, Plot3D or FASTlook is launched to view the data. The DWE also has helper applications for connecting to live camera views of the tunnel test in progress and for video conferencing with test engineers in the tunnel. All these helper applications run only on SGI workstations, and thus are only available to users with access to that platform.

ICS Visualization Technologies

Flow field solutions obtained through numerical simulations are generally very large data sets. A typical numerical solution contains five basic flow quantities (three components of momentum, density, and energy) per point, on a typical computational mesh (three components of position) of about a million points. The data sets then contain several million values per solution per time step for an unsteady flow. An analysis and understanding of the flow field by studying the vast information requires considerable training that is not always available to design engineers. Moreover, transferring complete data sets between remote sites is practically impossible. To assist the design engineers and to facilitate the data transfer we have developed novel scientific visualization techniques. Flow features are first extracted from the flow solver's output, and then are visualized via FASTlook and/or a viewer supporting the virtual reality modelling language (VRML). The following section discusses the various feature extraction and visualization techniques as well as the tools available to the DARWIN workspace environment.

Shock Wave Extraction

A shock represents a sudden change of fluid properties. Typically, a shock is witnessed when a body travels at supersonic or transonic speeds. The flow adjusts to a body by abruptly changing its pressure, density, and temperature. We have devised a method that takes advantage of shock attributes for a fast and clean method for extraction. The method is based on the assumption that at the shock location the shock surface is normal to the pressure gradient. The Mach number component is computed in the direction of the pressure gradient and a marching cubes algorithm is used together with various filters to generate a surface. The filters remove any theoretically implausible shock surfaces, such as expansion areas and surface segments that do not abide with the original assumption. To minimize numerical noise, it is verified that the pressure jump across the shock surface is within the range of pressure jump as is derived from the gas dynamics equations.

Tensor Field Visualization

Tensor data sets are at the heart of many engineering and physics disciplines, yet few methods have been devised for understanding and visualizing such data sets. In particular, second-order tensor fields are central to fluid mechanics. For example, stresses, strain rates, and Reynolds stresses are all tensor quantities. In traditional approaches, selected data are displayed using simple local icons depicting, for example, eigenvalues and eigenvectors at selected points. Through this data reduction process, valuable information is lost or discarded.

Since a tensor field is a continuous field it should be visualized as such. The approach is to trace the trajectories of the eigenvectors of the tensor field (referred to as hyperstreamlines[4]). Any symmetric tensor data set can be represented locally by a set of orthogonal eigenvectors and eigenvalues which contain all the information about the tensor data at a given point in space. Hyperstreamlines are tangent curves to the principle eigenvectors; the eigenvectors are ordered according to their eigenvalues, and a particular eigenvector is chosen, corresponding to the smallest, middle or largest eigenvalue. By integrating along the direction of the chosen eigenvector, a tangent curve is generated along which we can display, in an orthogonal manner, the remaining two eigenvectors. This can be done as a set of orthogonal vectors or ellipses having principle axes in proportion to the two eigenvalues.

In this manner a display is generated that takes advantage of the continuity of the data, and all information in the original data is retained.

Oil Flow Simulation

3-D separated flows play a significant role in aerodynamics because of the close relationship between separation and vortices, which are important structures of the flow far from the body. The first step in visualizing 3-D separated flows consists of depicting the structure of the vector field near the body, for which an adequate description is inferred from the skin-friction field. Numerically, the skin-friction field is simulated by representing the 2-D tangential velocity field one grid plane away from the surface of the body using arrows. This method mimics a visualization method that is commonly used by experimentalists, namely, the oil flow. Experimentally, the skin-friction field is studied by examining the streaks that form in an oil film on the surface of a body in a wind tunnel.

A recent major improvement in visualizing 2-D vector fields was made by adopting a new rendering technique, namely anisotropic textures. By generating textures, 2-D streamlines are rendered directly, without the need for integrating the vector field.[5,6] Textures provide an adequate solution to problems of accuracy, do not require an integration of the whole vector field, and create continuous images.

The use of textures in representing the skin-friction field provides the researcher with an image that can be analyzed using critical point theory and can be compared with images from experiments. By applying coloring based on pressure values on the body surface this technique combines oil-flow simulation with a simulation of PSP. Furthermore, it provides the means to analyze the relations between the skin-friction topology and the surface pressure.

Vortex Core Extraction

ICS employs new extraction and visualization techniques for vortex cores. The method is based on the observation made by Levy et. al.,[7] that vortex cores are streamlines along a locus of helicity maxima. By computing the gradient of the helicity field and following its trajectories we form tubes that delineate the path of the vortex core. The vortex core extraction method is still under development; however, it was successfully used to locate the cores for a wide variety of flows including open and close separation.

Data Visualization Tools

Once features have been extracted, and the primitives used to represent them have been created, there are various data-visualization tools available for displaying the results. For the most general viewing, primitives can be exported to VRML 1.0 for viewing. This allows for platform independent data analysis.

For scientific visualization, a simple viewer may not suffice. Many times the actual data values need to be known, or some data needs to be masked for a clearer representation of the essential characteristics. For this purpose, FASTlook was created as a helper application designed for more in-depth analysis of results attained from feature extractions. FASTlook provides all of the basics found in typical 3-D viewers (rotation, zooming, panning etc.) and allows for the manipulation of individual primitives. For example, an analysis of a flow about a wing may contain a grid representing the wing surface, surfaces representing shocks, hyper streamlines depicting the reversible momentum tensor, and tubes representing the vortex cores. Individual primitives can be hidden, removed, or even added. For example, the skin friction lines can be further added to the display. Color maps can be merged or modified, and Plot3D grids can be directly imported.

FASTlook was written using C++, ViewKit (C++ wrapper classes over X11/Motif), and OpenGL. FASTlook is intended to be run as a helper application under the DWE but can also be instantiated separately in a user defined C++ application.

Capabilities

The application of these various technologies brings new capabilities to design engineers. Both experimental and numerical data can be accessed, reviewed, and analyzed in more powerful ways. In this section we will describe how the DWE and the ICS are typically used.

Wind Tunnel Data Access

While a wind tunnel test is in progress, test engineers closely track the data being collected. The DWE can be used by engineers at the tunnel or at remote sites such as the customer's home office. Once logged in (Figure 3) the user can proceed to the home page of the current test (Figure 4). This screen displays the name of the test, various summary information, and a table of the most recent runs. The toolbar at the bottom of the page provides links to the current display and the user's authentication screen, plus links that launch helper applications for presenting the live camera view of the inside of the tunnel or for initiating a conference with tunnel personnel. The "Latest Data" table lists the most recent run numbers along with a few columns containing user-defined descriptive variables (such as average Mach number or average Reynolds number). If the user is interested in runs other than those most recently completed, a Database Query link is available to perform a database search to retrieve the runs of interest. Once the table is displaying the correct runs, the user can select the data to review by clicking the corresponding checkboxes of the runs of interest and then clicking the Data Review button

The Data Review page displays user-defined plots and tables of data for the selected runs (Figure 8). The top frame of the page contains links to the plots and tables displayed in the lower frame. For example, clicking the "C_L vs C_M" link in the top frame scrolls the bottom frame to display the graph displaying coefficient of lift versus angle of attack. The table in the top frame lists the selected runs and descriptive variables from the test home page plus links to additional data from that run.

The spreadsheet icon in the top table links to the data table for that run in the frame below (Figure 8). The user may specify which variables appear as columns in this table. The plot icon in the third column indicates that plots of pressure tap data are accessible. Clicking the plot icon brings up a new window with one or more graphing applets displaying the coefficient of pressure for various sets of taps on the model (Figure 9).

The presence of an icon in the PSP column of the data table or the run table indicates that PSP data was collected during that run or sequence. Clicking the icon in the run table brings up a window displaying a small-multiple view of all the PSP images recorded during that run (Figure 10). Clicking on the icon in the data table displays just the images collected at the sequence. From the small-multiple display, the user can bring up the PSP animation applet that was described earlier in this paper. If the user wishes to analyze any of the PSP images in more depth, clicking on an image launches exVis, the PSP analysis tool (Figure 7).

All of these pages are constructed dynamically by CGI scripts accessing the DARWIN meta database and retrieving and parsing data files from the DARWIN distributed file system. Thus, the pages always reflect the current status of the test. The scripts, in addition to adapting their output to a particular test, also configure the displays to the user's preferences. By using the preferences screen (Figure 11), the user can specify which variables appear in the tables and graphs. The DWE also keeps track of the state of various screens so that when the user returns, they will have the same appearance.

All the examples in this section have demonstrated review of data from a single test. The DWE also allows its users to compare data from multiple tests. To run a cross test comparison, the user selects runs from the initial run table, and instead of clicking the Review button, selects the Compare button. The selected tests are then added to the cross test comparison screen (Figure 12). From that screen, any set of runs can be selected and reviewed together, much the same way as runs from a single test are reviewed.

CFD Analysis

In the process of wingdesign, the engineer is mainly interested in the surface pressure coefficient distributions. These are directly affected by the shock location, whether separation and shock induced separation exist, the locations of the separation lines, and the location of vortices. The ICS feature extraction technology provides the tools to display the above features and to manipulate the display so that the engineer can explore the numerical results, compare them to experiments and alter the model accordingly.

In order to show the effectiveness of the workspace environment, two wing analysis test cases are presented. The first case consists of the oblique all wing, which appears as an experimental model in the DWE examples of the previous section. The flow conditions are angle-of-attack $\alpha = 3.0°$, Mach number M = 1.6, and Reynolds number of Re = 5.53 million. The DARWIN database contains only the numerical solution containing regions of most interest to a design engineer, namely, surface information. Thus, the numerical data included information limited to data on the surface and on the shell of points one grid point away from the surface. This limited data prevents ICS from using the shock and vortex extractors, but allows visualization of the skin-friction field and the surface pressure. The results are shown in Figure 13.

In the following test case, we have provided a complete representation of the transonic flow about an ONERA M6 wing. There is extensive experimental data that reinforces the various feature extraction findings. The computational mesh consists of a 269 X 35 X 67 C-O mesh and the flow conditions are angle-of-attack $\alpha = 5.06°$, Mach number M = 0.8447, and Reynolds number of Re = 7.61 million. The results of the feature extraction process are presented in Figure 14. The skin-friction field colored by the pressure on the body surface is used to also show the geometry of the wing. Blue colors denote regions of low pressure and red colors denote regions of high pressure. The surface of the shock is presented by a gray surface and the vortex core is presented by a red tube. The figure includes only the a small part of the wing-tip vortex which trail behind the wing all the way to the edge of the computational mesh.

Apparent from the figure are the separation lines behind the shock surface and the separated regions that are clearly illustrated by the skin-friction field topology. The colored texture presented together with the shock surface illustrate the effects of the shock on the flow. Evident are the pressure jump across both parts of the λ shock and the change in flow topology across the main shock.

Future Work

At the present time, both the DWE and the ICS are mature prototypes. They are currently in use at NASA and Stanford and are rapidly developing into full-fledged applications. The focus of our work in the coming year will be to bring these two components together to allow combined analysis of experimental and numerical results. For wind tunnel experimentalists, we would like to provide a system for reviewing existing numerical solutions and comparing them to tunnel data as it is collected. For this task, the DWE will be extended for managing the results of CFD simultations. If no comparable numerical results exist, we plan to provide a mechanism for launching a flow solver to produce an appropriate solution. Toward this end, work has begun on a “solver assistant” that leads the engineer through the setup of a flow solver and provides advice on configuring it correctly for a valid solution. Two keys to producing a successful CFD solution are properly configuring the input files and understanding the domain of applicability of the solver code. The solver assistant checks the wind tunnel conditions proposed for the simulation and informs the user of whether the solver code is capable of producing a physically valid solution for the given situation. If the code is appropriate, then the necessary input files are generated and configured automatically so that the engineer does not have to bother with details of file formatting and naming conventions required by the solver. The solver assistant will allow users to setup and launch flow solver codes via a web interface similar to those used in the DWE. Fluid dynamicists could also use this system to launch codes and track the solutions, as well as have access to experimental data for analysis and review.

Summary

The DARWIN Workspace Environment is designed to provide the aerospace customer of the future with the necessary information access to greatly improve the design cycle process. By gleaning more knowledge from experimental and numerical data, the DWE provides the capability to perform true design cycle iterations in a single test entry. Under the guise of the Aeronautics Design and Test Environment (ADTE) project, we will continue this work with the goal of further integrating experimental and numerical methods to provide the best aeronautics design facility possible.

Acknowledgments

Rajesh Batra and Yuval Levy are partially supported by NASA under contract NAG 2-911-2 which includes support from the NASA Ames Numerical Aerodynamics Simulation (NAS) Program and the NASA Ames Fluid Dynamics Division, and also by NSF under grant ECS-9215145.

The authors would like to thank the NAS Data Visualization group for the use of their PSP visualization tool, exVis.

References

1. Koga, D. J., Korsmeyer, D. J., and Schreiner, J. A., "DARWIN Information System of NASA—An Introduction," AIAA-96-2249, 19th AIAA Advanced Measurement and Ground Testing Technology Conference, June 17–20, 1996, New Orleans, LA.

2. Korsmeyer, D. J, Walton, J. D., Gilbaugh, B. L., "DARWIN—Remote Access and Intelligent Data Visualization Elements," AIAA Paper No. 96-2250, 19th AIAA Advanced Measurement and Ground Testing Technology Conference, New Orleans, LA, June 17–20, 1996.

3. Schreiner, J. A., Trosin, P. J., Pochel, C. A., and Koga, D. J., "DARWIN—Integrated Instrumentation and Intelligent Database Elements," AIAA-96-2251, 19th AIAA Advanced Measurement and Ground Testing Technology Conference, June 17–20, 1996, New Orleans, LA.

4. Delmarcelle, T. and Hesselink, L., "Visualizing second-order tensor fields with hyperstreamlines," Computer Graphics and Applications, vol. 13, no. 4, pp. 25–33, 1993.

5. Cabral, B. and Leedom, L. C., "Imaging vector fields using line integral convolution," Computer Graphics (SIGGRAPH'93 Proc.), pp. 263–272, 1993.

6. van Wijk, J. J., "Spot noise. Texture synthesis for data visualization," Computer Graphics, vol. 25, no. 4, pp. 309–318, 1991.

7. Levy, Y., Degani, D., and Seginer, A., "Graphical Visualization of Vortical Flows by Means of Helicity," AIAA Journal, vol. 28, no. 8, pp. 1347–1352, 1990.

Figures

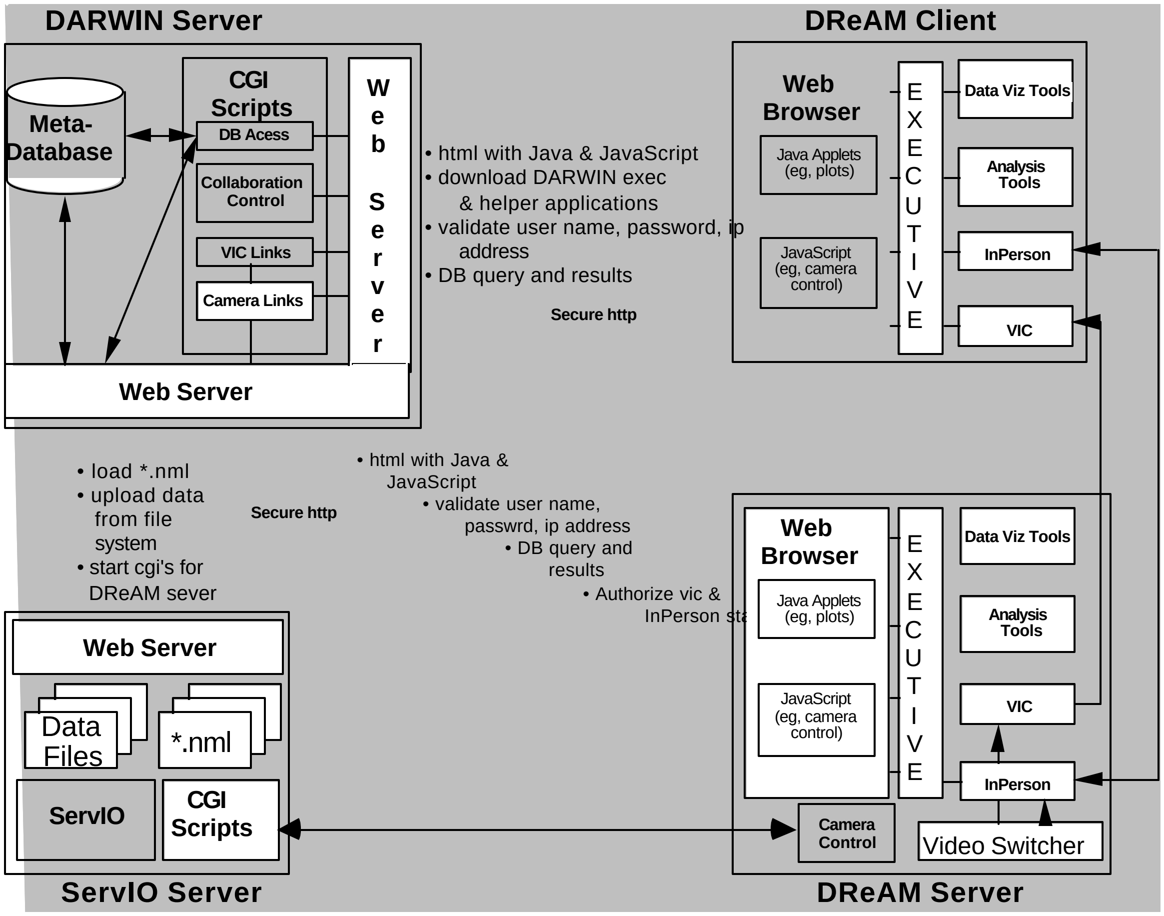

Figure 1. DARWIN Architecture

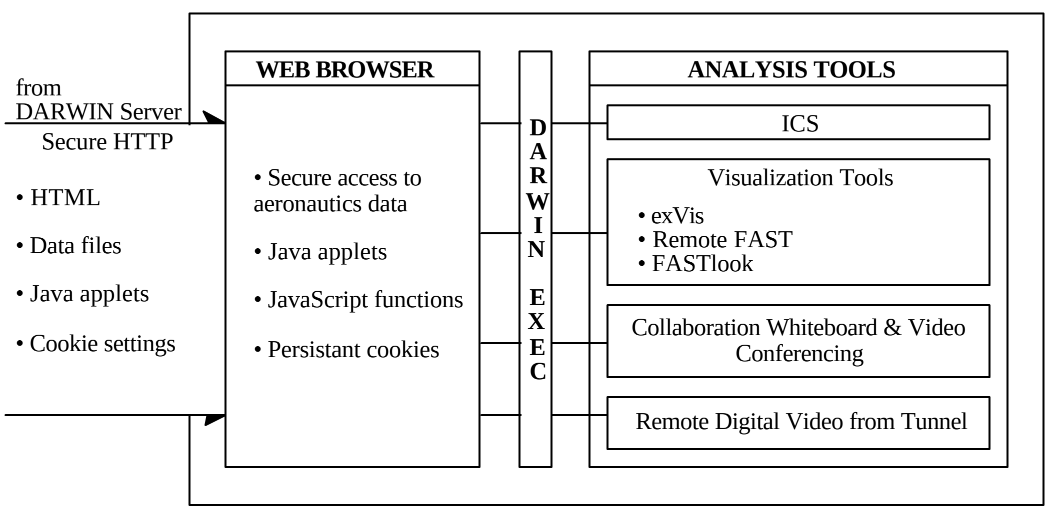

Figure 2. DReAM Client

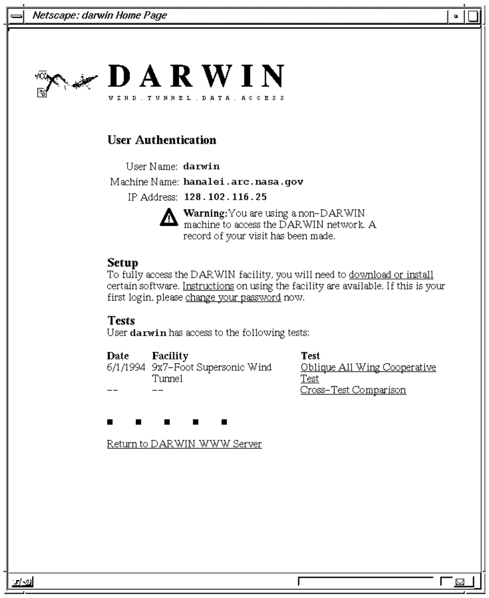

Figure 3. Authentication Screen

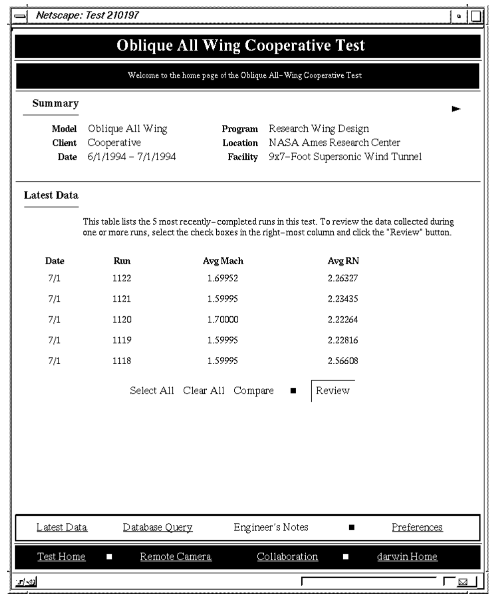

Figure 4. Test Home Page

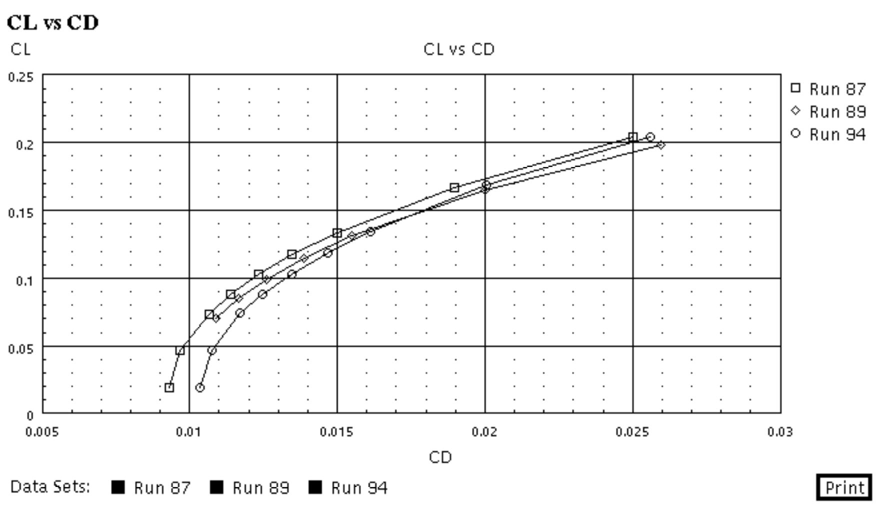

Figure 4. Graphing Applet

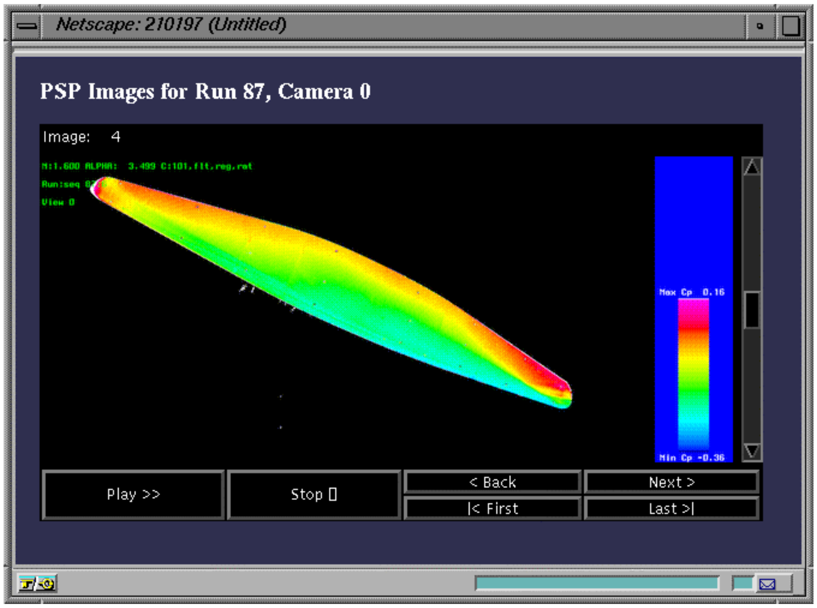

Figure 5. Animation Applet

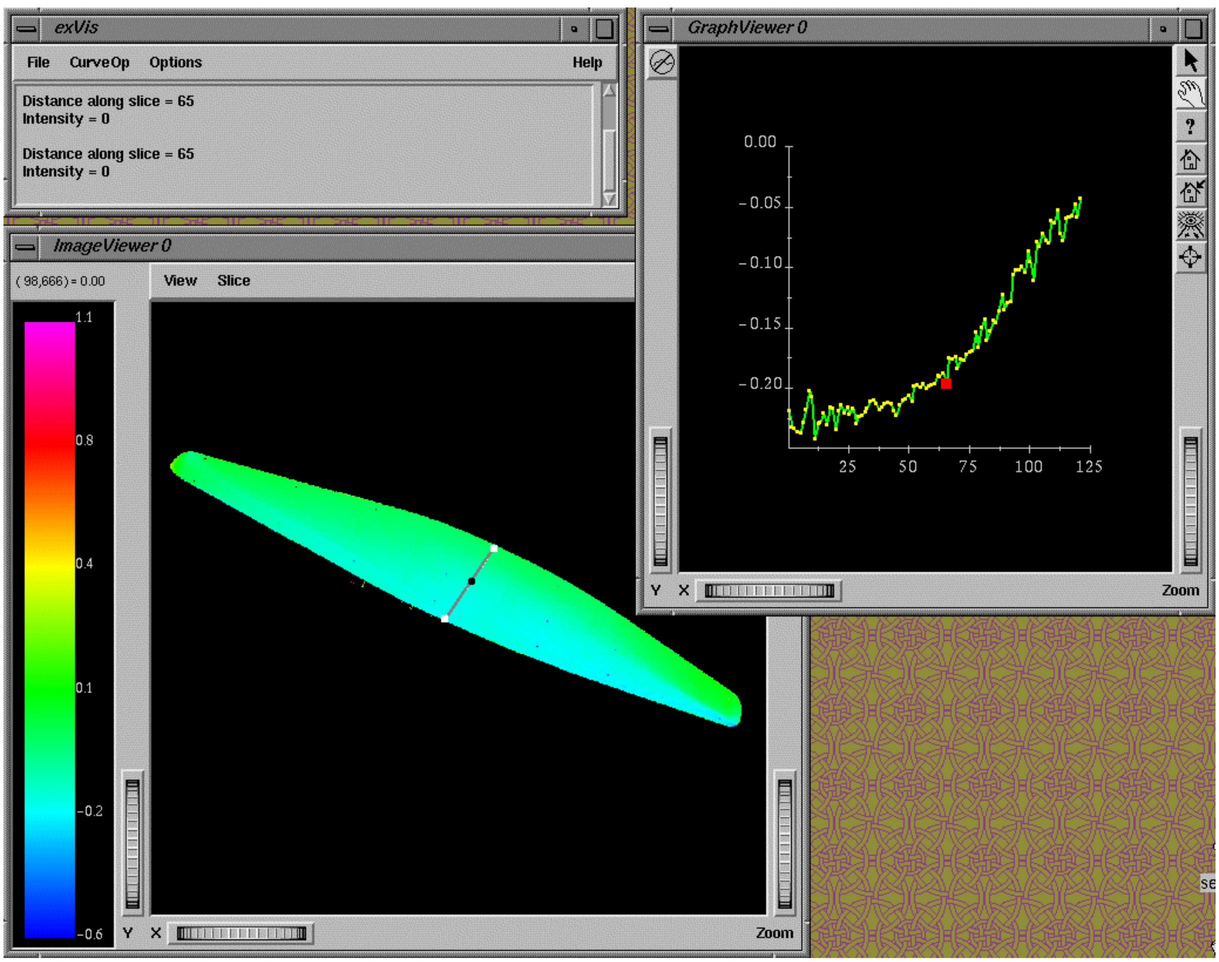

Figure 6. exVis

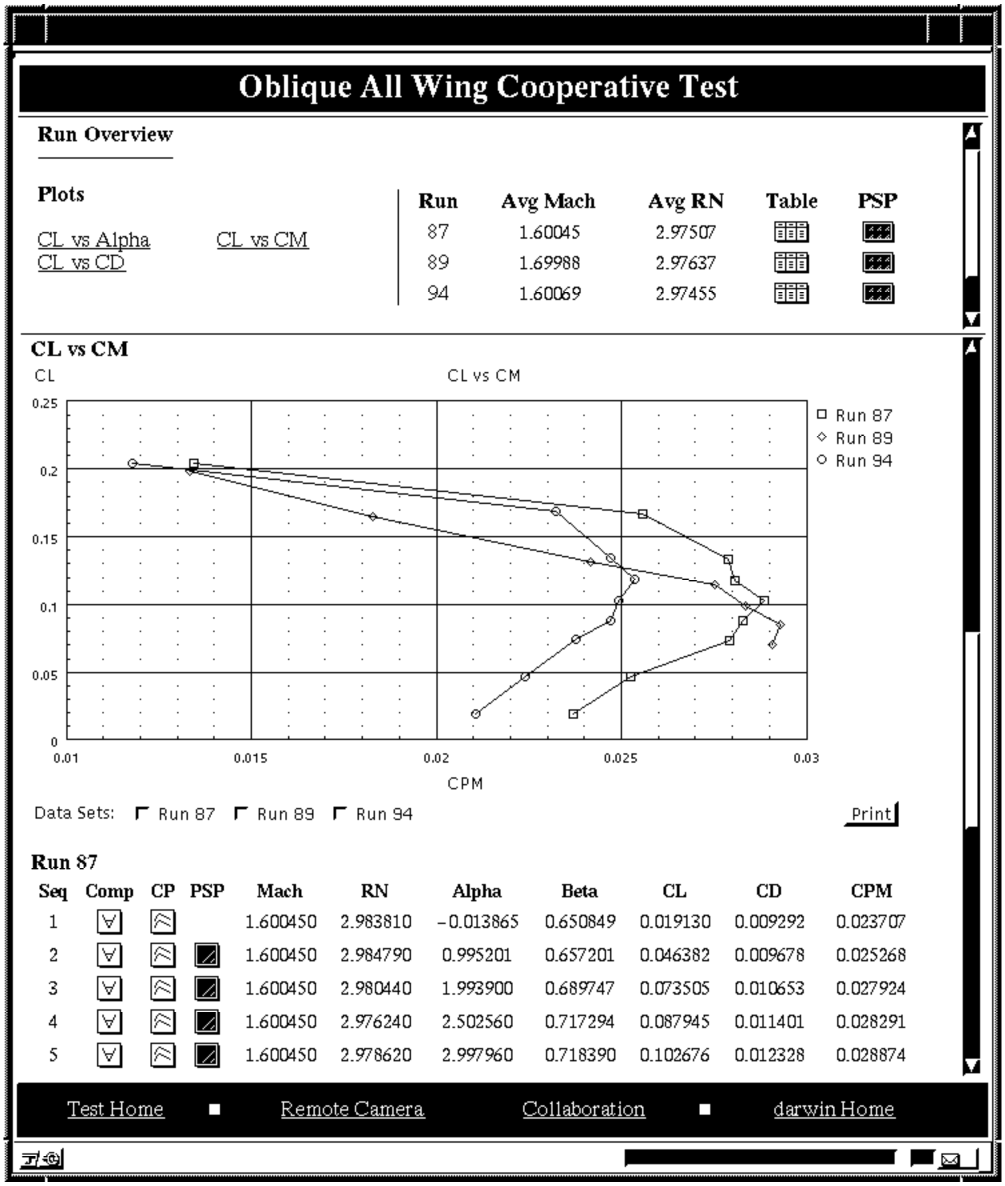

Figure 8. Data Review Page

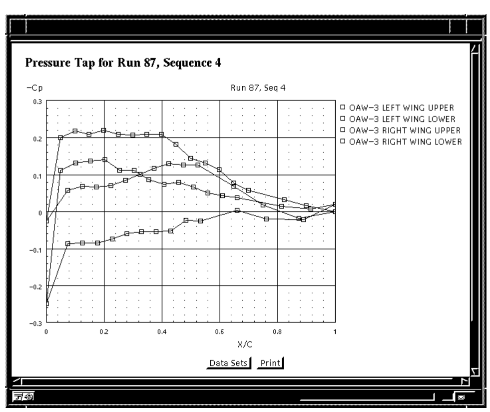

Figure 9. Pressure Tap Data Plots

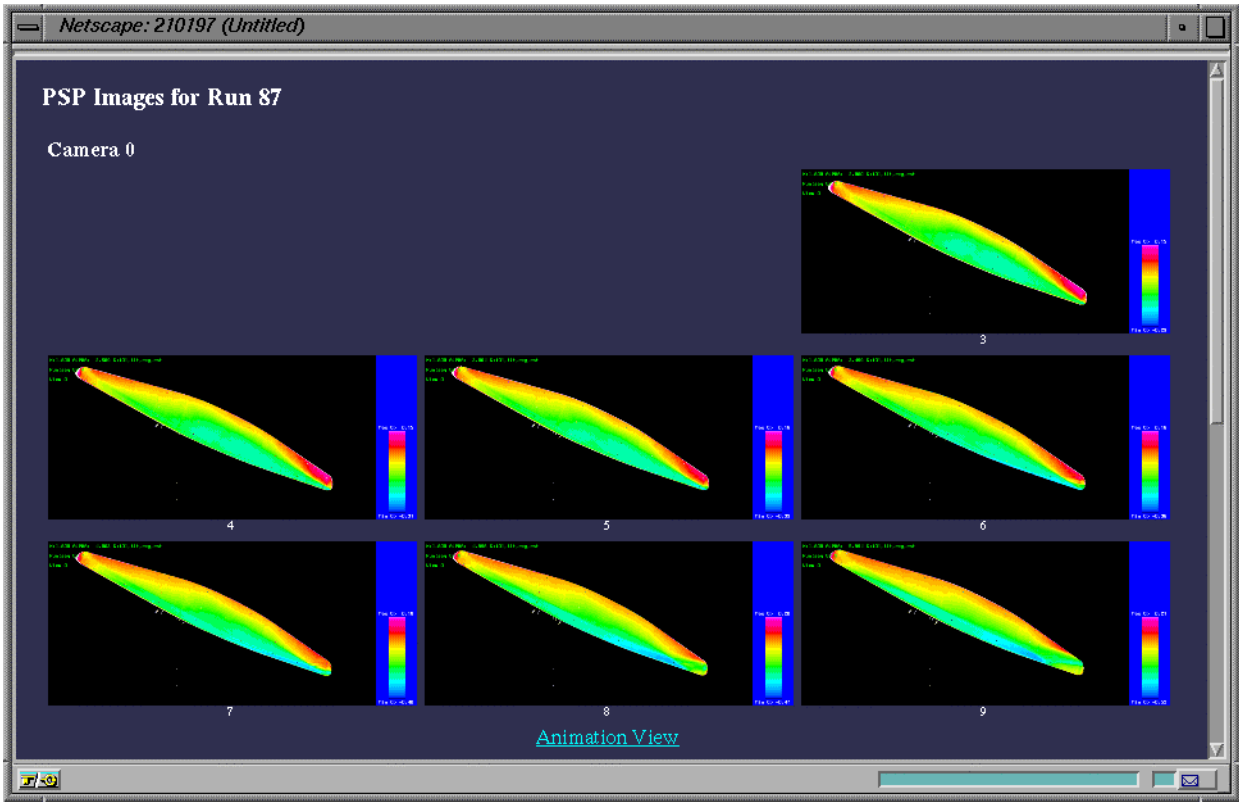

Figure 10. Small-multiple Display of PSP Images

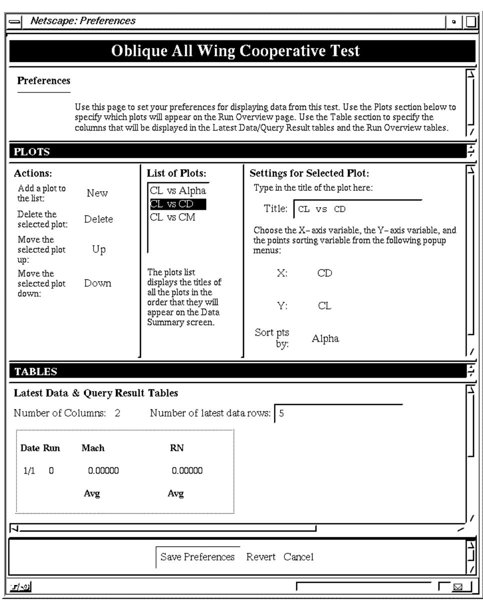

Figure 11. User Preferences Screen

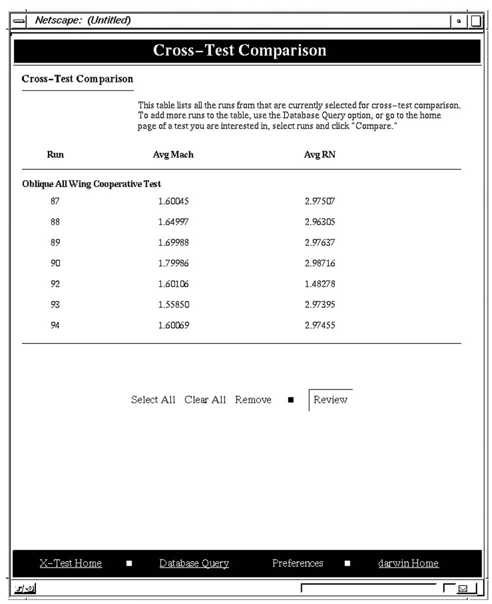

Figure 12. Cross-Test Comparison Screen

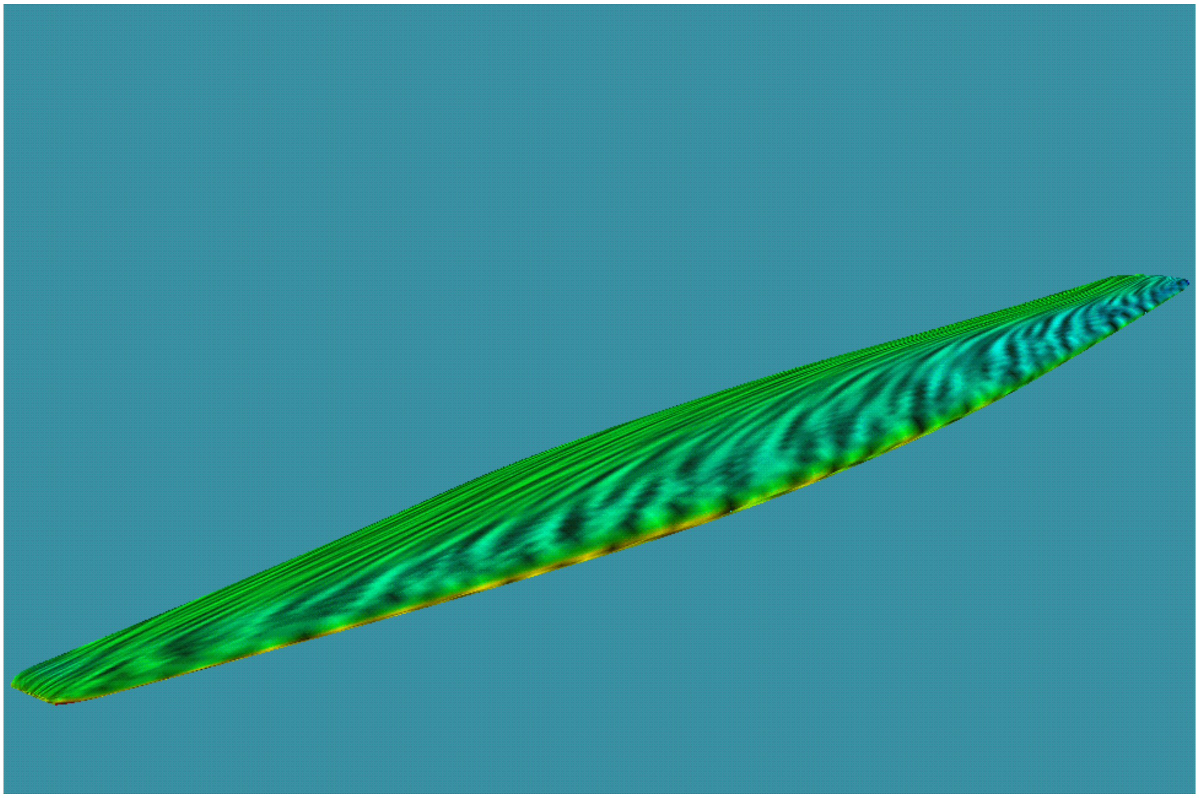

Figure 13. Oblique All Wing Showing Skin-Friction Field

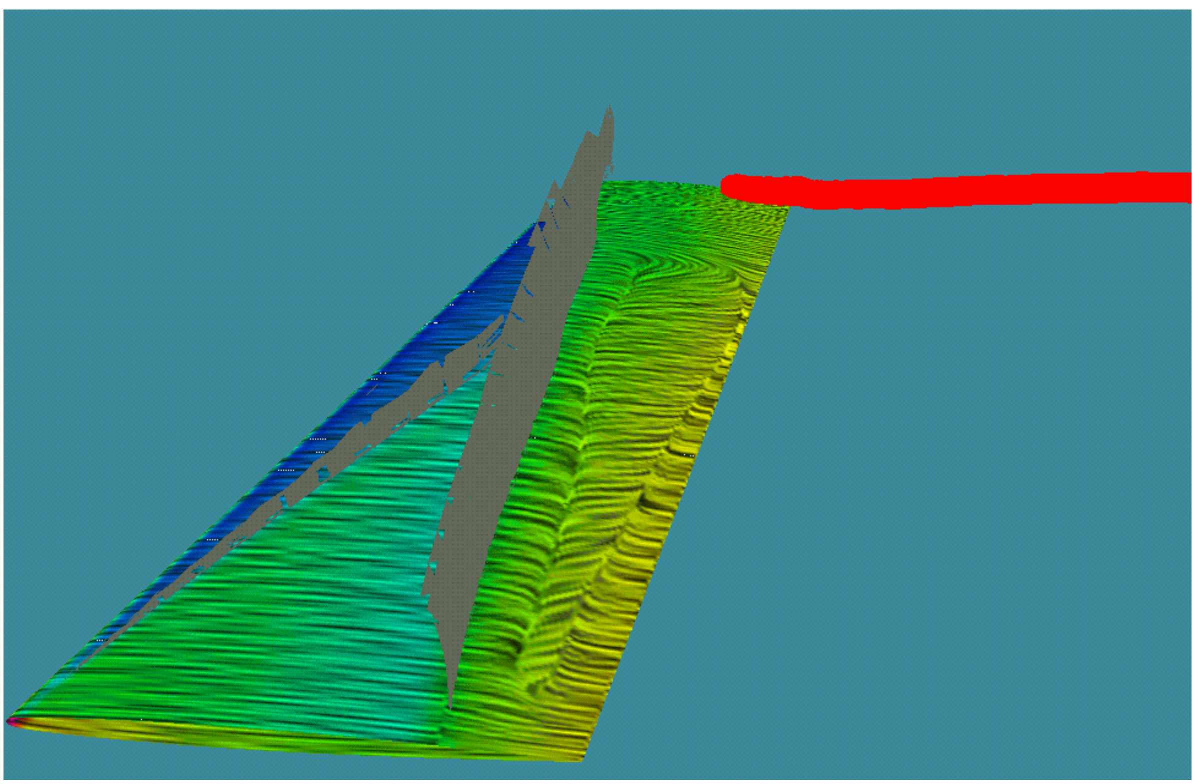

Figure 14. ONERA M6 Wing Showing Skin-Friction, Shock and Vortex